The Cornerstone AUV Navigator

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LONG-TERM GOALS

Bluefin's business focus is the design and manufacture of autonomous underwater vehicles for use in military, scientific, and commercial applications. For many AUV missions, accurate navigation that does not depend on acoustic beacons in the operating region is one of the primary remaining technical hurdles. This effort will address this need through the creation of the Cornerstone AUV Navigator, an extensible, flexible, low-cost AUV navigator that will solve the navigation needs of a variety of AUVs.

OBJECTIVES

The objective of the Cornerstone AUV Navigator (CAN) effort is to create a high-accuracy navigation solution tailored for use on AUVs (i.e., low power consumption, small size, low cost) using a "system of systems" approach. The CAN will be extensible to new techniques as they become available, flexible to adding new sensors, and adaptable to lower-accuracy, lower-cost applications. The fruits of this effort will be made available to other ONR-funded AUV programs.

Our technical objectives are to enable AUV missions with:

- Navigation accuracy of 0.1 % of distance traveled without DGPS and/or acoustic aiding,
- Over-the-horizon (> 20 nmi) ingress/egress to the area of operations,
- Extended periods of fully submerged operation without DGPS or acoustic aiding,

APPROACH

In a traditional INS/DVL integration, incorporating additional navigation information to improve the fix has been difficult, if not impossible, because the navigation code was inaccessible inside the INS. The CAN takes a different approach. Mechanized by an extended Kalman filter running on a dedicated, external navigation computer, the "Shadow" navigation code allows the CAN system to be readily extensible. Software hooks will facilitate adding external navigation information from sources

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14. ABSTRACT
Bluefin???s business focus is the design and manufacture of autonomous underwater vehicles for use in military, scientific, and commercial applications. For many AUV missions, accurate navigation that does not depend on acoustic beacons in the operating region is one of the primary remaining technical hurdles. This effort will address this need through the creation of the Cornerstone AUV Navigator, an extensible, flexible, low-cost AUV navigator that will solve the navigation needs of a variety of AUVs.

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such as DGPS, acoustic systems such as LBL or USBL, and external position updates communicated via an acoustic modem. In addition, new feature-based navigation algorithms can be adapted for later incorporation into the extensible AUV navigator. Feature-based navigation methods offer the potential of achieving bounded errors for long-duration missions, offering a method to avoid the need for acoustic beacons or surfacing for GPS resets. Furthermore, the modular framework developed in the CAN project facilitates the addition of new navigation sensors to the CAN system. This allows the navigation accuracy of the CAN to be tailored to the requirements of a particular mission or AUV.

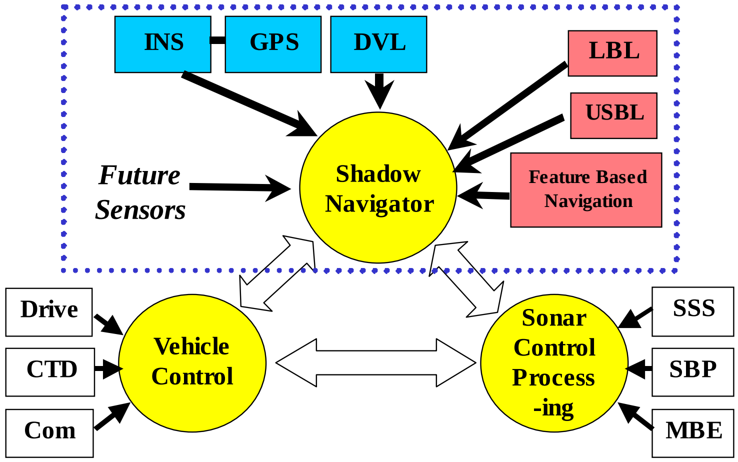

Figure 1: The Cornerstone AUV Navigator concept consists of a system of systems (blue-dotted box) coordinated by the "shadow" navigator code running on a dedicated navigation engine. The shadow navigator communicates with vehicle control and payload control nodes on-board the AUV.

The initial implementation of the Cornerstone AUV Navigator, ***Figure 1,*** will exploit recent technical advances to create a high-performance navigator tailored for operation on an AUV. The CAN will use state-of-the-art sensors including a Litton LN-250 INS and a 300 kHz Doppler Velocity Log (DVL) from RD Instruments. The Litton LN-250's low power consumption, small size, and navigation-grade INS performance make it ideally suited for use on an AUV. The 300 kHz Doppler Velocity Log from RD Instruments has been employed on several Bluefin AUVs and provides an important external measurement of AUV velocity to null out INS drift errors. After this project is completed, the CAN will be made available as a community resource to other government-funded AUVs.

We have assembled a "team of experts" drawn from the leading players in each component technology area. The prime contractor, Bluefin Robotics, has extensive experience in the design and manufacture of AUVs. The Charles Stark Draper Laboratory has conducted research programs in the navigation of undersea vehicles, both manned and unmanned, for over 30 years. The Litton LN-250 INS and the RDI 300 kHz DVL are high-performance instruments that are designed for high-volume, low-cost, sales. Litton and RDI are both widely recognized as leaders in their respective areas of expertise.

WORK COMPLETED

The Cornerstone AUV Navigator (CAN) project is an effort to produce a state-of-the-art navigation system for AUVs based on a flexible, modular architecture. The CAN work has been split between several organizations: Bluefin has conducted the system architecture design, system electrical

integration, software refactoring and integration, system integration into the AUV, and overall project management; Litton Guidance and Control Systems has provided the LN250 INS system along with modifications to the LN250 hardware and software to support the CAN program; RD Instruments has developed a DVL error model for incorporation into the navigation filter; and the C.S. Draper Laboratory has supplied the navigation filtering code. The work completed by all participants is summarized below:

Bluefin: Bluefin has conducted the implementation and integration of the CAN system architecture. Bluefin has finished refactoring and porting the navigation filtering code to the QNX real-time operating system. Bluefin has also finished interfacing all navigation sensors with the navigation computer, including the precision timing hardware. The interface specification for controlling the navigation system from the main vehicle computer has also been implemented.

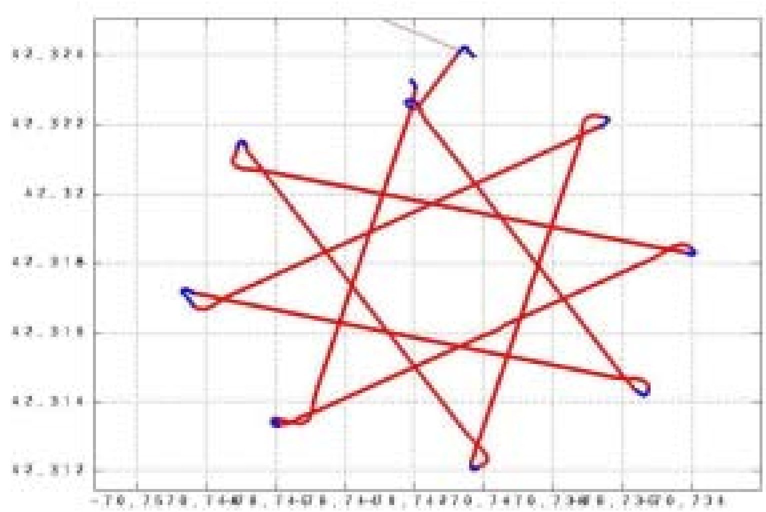

Figure 2. Preliminary sea trials of the CAN system integrated into a survey-class AUV focused on star missions such as this.

Bluefin has completed the in-motion ("van") tests with the LN-250. These tests verified the operation of the moving-base alignment software inside the CAN. Bluefin has also completed preliminary performance testing of the CAN on a survey-class AUV. Results of these initial tests are included below.

Draper: The C. S. Draper Laboratory delivered a "beta" version of the navigation filter code to Bluefin for refactoring and integration. Draper has also provided technical advice and assistance during integration and initial performance testing of the CAN.

Litton: Litton's portion of this contract was, for the most part, completed by the end of FY2001. Additional technical support was provided to aid in final integration of the LN250 with the overall system.

RD Instruments: RDI has developed a more sophisticated DVL error model that Bluefin has integrated into the CAN system. RDI has also provided input into the sea trials test plans and technical advice in tuning the improved DVL error model to match measured data.

RESULTS

Initial implementation and testing of the Cornerstone AUV Navigator program is now complete. The LN250 underwent a series of bench and "van" test to assure acceptable performance. The complete CAN system was then integrated into a survey-class vehicle for sea testing.

The preliminary sea tests focused on characterizing the performance as implemented. Figure 2 shows the track of a typical star mission. Results from this mission are shown in Figure 3. Errors are calculated only when the vehicle surfaces for a GPS fix. By the end of this 10 km mission, navigation error was 0.1% of distance traveled. The CAN architecture used in these trials made use of the improved DVL error model. Continued tuning is expected to yield improved results.

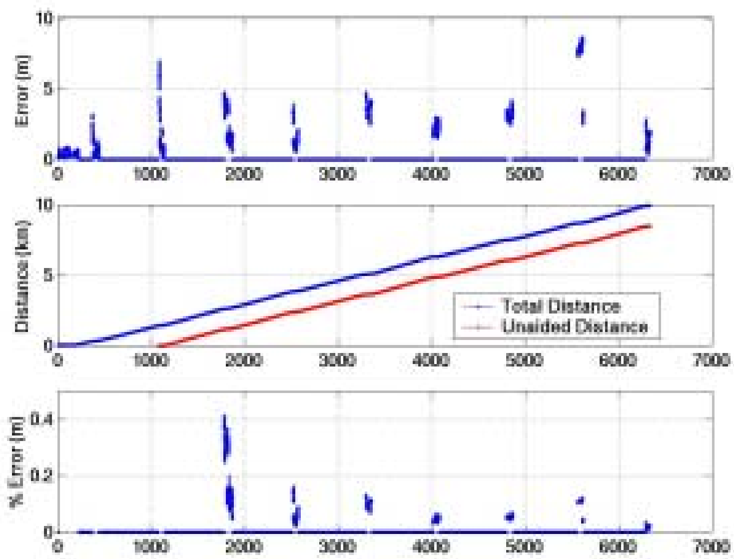

Figure 3. Performance of the CAN system during a typical star mission. At the end of this 10km mission, navigation error (as compared with measured GPS position) was below 0.1% distance traveled.

Two further issues might fruitfully be addressed at this point. First, navigation error calculated as a percent of distance traveled is highly dependant on the mission path. In missions such as that shown, errors can be reduced due to averaging out of sensor biases. This occurs when the orientation of survey legs is distributed in angle. Alternate test missions might reveal additional details about the performance of the CAN filter.

Second, it is harder to analyze performance of the system when the total navigation error is on the same order as the GPS measurement error. Longer survey missions would allow more accurate analysis of the final error for this reason.

IMPACT/APPLICATIONS

The Cornerstone AUV Navigator represents a major technological leap forward in AUV navigation. It will be the first low-power, low-cost, high-accuracy INS/DVL-based navigation solution suitable for operation on the new generation of small AUVs that have arisen in the last decade. The Cornerstone AUV Navigator is an enabling technology for a variety of potential missions to be conducted by these AUVs. Several ONR-funded vehicle programs could benefit from the efforts of this program.

TRANSITIONS

Bluefin estimates that the commercial AUV market will grow to around one hundred units per year. The market will be split between inspection and mapping AUVs, both requiring INS/DVL navigation. Additional sales can be expected from non-AUV platform such as ROVs and towed systems. Bluefin intends to make the CAN available as a COTS product both directly and through distributors.

RELATED PROJECTS

The *Battlespace Preparation AUV* (BPAUV), shown in Figure 4, is an ONR-funded program to produce a modular AUV for autonomous bottom mapping and classification. Due to its modular section design, the BPAUV is capable of carrying different or additional sensors and payloads.

Figure 4: The Battlespace Preparation AUV (BPAUV) provides autonomous bottom mapping/classification and target localization capabilities for MCM missions.

As part of the Autonomous Operations Future Naval Capabilities program, the Cornerstone AUV Navigator will in incorporated in the BPAUVs. These upgraded vehicles will be the platform for the Communications/Navigation Aid vehicle. In this role, the LN250-based version of the CAN will be combined with a unique acoustic signaling scheme to “transfer” the high-accuracy navigation capabilities of the CAN-based C/NA to a cadre of SCM and RIN vehicles.

A second program, the *US/UK Collaboration on UUVs for MCM Applications*, for which Bluefin has built two BPAUV-style vehicles, will also use the Cornerstone AUV Navigator to provide precise navigation and attitude information to the high-resolution Synthetic Aperture Sonar (SAS) payload

carried by the AUV Reliant (the US AUV in this multi-national program). The Cornerstone AUV Navigator has already been installed on the AUV Reliant and initial sea trials have been successfully completed.